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OBSERVATIONS OF ULTRAVIOLET VARIABILITY IN RV TAURI STARS

Edward W. Brugel

Center for Astrophysics
and Space Astronomy
University of Colorado
Boulder, Colorado

Jason A. Cardelli

Department of Astronomy
University of Wisconsin
Madison, Wisconsin

ABSTRACT

During the tenth IUE observing epoch we initiated a program to monitor the ultraviolet variability in several RV Tauri stars. In particular, the Mg II region was investigated as a potential probe of atmospheric shocks, which are believed to be associated with the pulsational variability of this class of objects. We present the observations, a description of the spectra and our preliminary findings for two objects – V Vul and AC Her. In particular, the Mg II emission does vary significantly during the cycle; major changes in the emission line strength occur on a time scale much less than 0.2 in phase; and as the UV (and optical) continuum flux increases, the Mg II lines decrease and increased emission may be seen at 2823Å, 2844Å, and 2900Å.

Keywords: *stars: variable – stars: RV Tauri – stars: atmospheres – shock waves – lines: emission*

I INTRODUCTION

Among the variety of pulsationally unstable stars, RV Tauri stars stand out as a distinct and unique class of variables. This class of stars is characterized by alternating deep and shallow minima and tend to show spectral variations indicative of metal poor supergiants (II-Ib, Ia) of type F, G, and K. Their periods, taken between successive deep or shallow minima, are typically in the range 30-150^d with the majority being between about 50-100^d. From a spectroscopic standpoint, RV Tauri's fall into three basic groups as first outlined by Preston et al. (1963). Type A consists of stars exhibiting features characteristic of G-K stars. Type B consists of stars exhibiting peculiar F type spectra as indicated by the continua shape and the strength of the hydrogen and Ca II lines. Finally, type C objects tend to share the same characteristics as type B with the difference being that CN and CH absorption is weak or completely absent.

Furthermore, RV Tau variables often exhibit behavior indicative of stars undergoing mass loss. Many frequently show emission in the Balmer lines on the rise from primary and secondary minimum, while through other phases the higher Balmer lines appear partially filled in while Hα can remain in emission. A few stars (e.g. AC Her) have been studied optically at high spectral resolution and tend to display line doubling and weak metallic-line emission near primary minimum implying *moving atmospheric layers* and *shock waves* similar to Mira variables. For a recent review on atmospheric shocks see Willson and Bowen (1985). Finally, nearly all of the observed RV Tau stars show moderate to strong IR emission excesses indicating the presence of large amounts of circumstellar material. This, along with the presence of molecular absorption at phases where it is not expected to occur in the atmosphere of the star (the absorption probably arises in circumstellar gas shell(s) separate from the dust) as well as large variable polarization, indicate that *mass loss is fundamental* to RV Tau behavior and may provide a link to their evolutionary state.

II OBSERVATIONS

During our tenth year *IUE* program we monitored in low dispersion the Mg II variability of several RV Tauri stars, concentrating on the following four objects: AC Her, V Vul, EP Lyr and UU Her. In addition, several high dispersion observations were obtained of U Mon. Unfortunately, varying degrees of phase coverage were obtained for each, and no object has complete phase coverage over an entire cycle. Detailed spectrophotometric phase coverage (intervals of $\Delta\phi \approx 0.1$) during the course of a variable star's cycle is extremely useful since it provides essentially a continuous "history" of a star's atmospheric variations. However, gaps in the phase coverage and an insufficient sampling rate can make the "history" difficult to interpret. For this reason, we will concentrate herein on the two stars for which we have the best phase coverage – V Vul, a Preston type 'A' star, and AC Her, which is Preston type 'B'. A log of the IUE observations and summary of the detected Mg II strengths, either emission or absorption, appears in Tables I and II.

The low dispersion spectra were extracted from the spatially resolved line-by-line file provided by IUESIPS and then merged. The net spectra (gross - background) were then converted to a flux scale using the absolute calibration

of Cassatella and Harris (1983) Though there are possible systematic errors in the absolute fluxes, the relative flux measurements are not similarly affected since all spectra were processed with the same calibration. A weak to moderate ultraviolet continuum was detected at and longward of 2500Å for most of the low-dispersion observations. The significant variability in the UV continuum may contribute to the changes seen at Mg II. We estimate that the uncertainty in the integrated flux measurements for V Vul does not exceed ±10%.

Table I
LWP Observing Log – V Vul

Julian Day 244+	Phase† (Opt.)	LWP	Exp. min	MgII Flux ergs cm^{-2} s^{-1}
7064.10	0.55	11722	30	3.93×10^{-13}
7075.03	0.69	11803	18	3.16×10^{-13}
7087.79	0.87	11907	30	3.12×10^{-13}
7088.76	0.88	11917	40	2.40×10^{-13}
7102.82	0.07	12001	30	1.62×10^{-13}
7114.70	0.22	12094	40	1.39×10^{-13}
7117.95	0.26	12125	10	$< 1.00 \times 10^{-13}$
7133.70	0.47	12220	40	1.57×10^{-13}
7142.61	0.59	12267	40	2.72×10^{-13}

† - assumes max. light (phase 0.0) on JD 2447098

Table II
LWP Observing Log – AC Her

Julian Day 244+	Phase† (Opt.)	LWP	Exp. min	MgII EW-Å
7064.01	0.34	11720	3	17.98
7074.96	0.48	11801	3	15.60
7088.80	0.67	11918	3	15.39
7102.92	0.85	12003	10	12.50
7102.95	0.85	12004	3	13.88
7114.65	0.04	12093	10	12.28

† - assumes max. light (phase 0.0) on JD 2447114

II.1 Description of the V Vul Spectra

As evident from figure 1, the spectra of V Vul show a distinct Mg II emission at almost all phases. Starting with our first observation at optical phase 0.55 (≈ minimum light) the Mg II line strength is at a maximum and the UV continuum is very weak. With increasing phase from 0.55 through maximum light (at phase 0.0) to phase 0.22 the Mg II flux shows a smooth decline. In contrast, the UV continuum longward of 2800Å shows a marked increase during the part of the cycle. There is also a hint of emission at λ 2823Å, 2844Å and 2900Å (see figure 1, phase 0.07 – 0.26). These are probably FeI lines, particularly the two shorter wavelength lines which are known MgII/FeI fluoresence lines (Carpenter et al 1988). The Mg II emission appears to reach a minimum near phase 0.26 while the UV continuum seems unaffected from phase 0.07 to 0.47. By phase 0.59, the emission in Mg II is approaching the maximum strength observed in the previous cycle at phase 0.55, while the continuum has faded drastically.

II.2 Description of the AC Her Spectra

AC Her presents a similar yet distinctly different form of UV continuum and Mg II variability (see Figure 2). In this case, the Mg II line is generally seen in absorption, though at some phases the absorption is apparently partially filled in by emission. In low dispersion the anticipated Mg II emission cannot be disentangled from the absorption and high dispersion data are obviously required. Starting at phase 0.34 the Mg II absorption feature is rather shallow and the continuum is quite weak. As one progresses in phase to 0.48 through 0.67, the Mg II absorption deepens, the continuum strengthens and there appears some slight evidence for emission at 2900Å. Only two tenths of a phase later, at phase 0.85, the absorption is significantly reduced and so is the continuum. Subsequently, there is little detected change through to maximum light, which was observed at phase 0.04.

RV Tauri stars are known for showing extreme cycle to cycle variations, even AC Her which is one of the most regular of the class show distinct differences from one cycle to the next. As an illustration, data taken in 1984 by Baird and Cardelli (1985) show significant Mg II emission at their phase 0.61, while our observations at phase 0.67 show close to a maximum absorption.

III DISCUSSION

The use of IUE low dispersion spectra for the purpose of studying atmospheric shocks and mass loss has shown promise for the Mira variables (Brugel, Willson, and Cadmus 1986, Brugel et al. 1987). This is particularly true when these data are combined with theoretical models such as those by Bowen (1988). Similarly, initial though phase limited observations had been attempted for a few RV Tau stars (Dawson and DuPuy, 1986). In an approach complimentary to the Mira investigations, we have endeavored to extend the technique to the hotter and shorter period RV Tauri stars. As very preliminary results we note three aspects apparent in the observations presented here: (1) the Mg II emission does vary significantly during the pulsation cycle for some RV Tauri stars; this emission variability does maintain phase coherence with the optical phasing; and it is undoubtedly associated with the propagation of an atmospheric shock; (2) major changes in the Mg II emission line strength occur on a time scale much less than 0.2 in phase, which was our sampling frequency (e.g. the Mg II flux in V Vul decreased from 2.40×10^{-13} ergs cm^{-2} s^{-1} to approximately zero in less than 22 days); and (3) high dispersion observations are required for AC Her in order to disentangle the Mg II emission from atmospheric absorption. In addition, the low dispersion spectra for V Vul hint at asymmetric structure in the Mg II emission, which in high dispersion may yield information on the atmospheric velocity distribution in the post shock region.

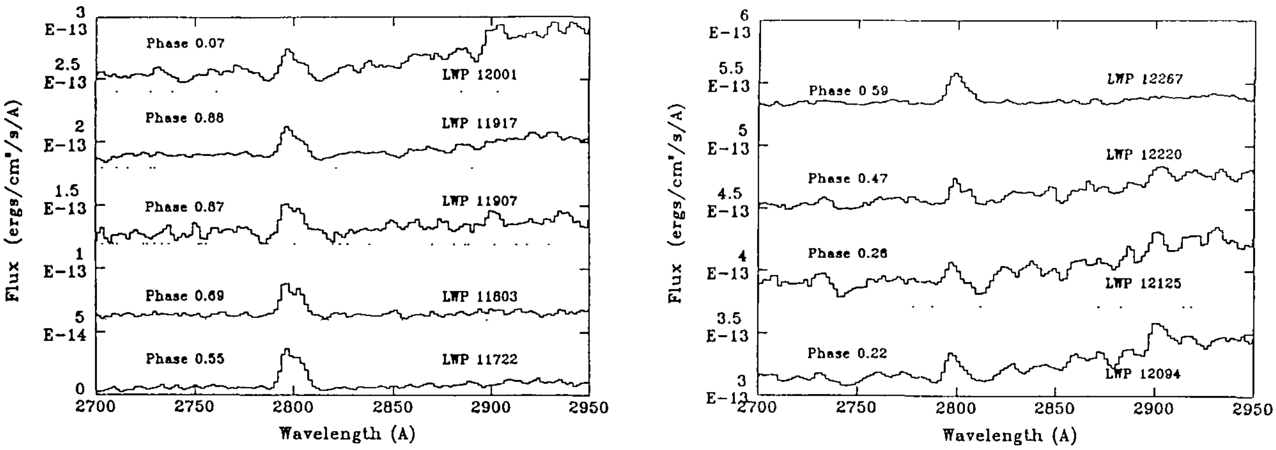

Figure 1: A series of nine low dispersion LWP spectra of V Vul are presented. An offset in flux has been added to each successive spectrum and the corresponding zero flux levels are indicated by the dashed lines. Note the smooth decline in the integrated Mg II from phase 0.55 through 0.26, and the contrasting increase in the UV continuum.

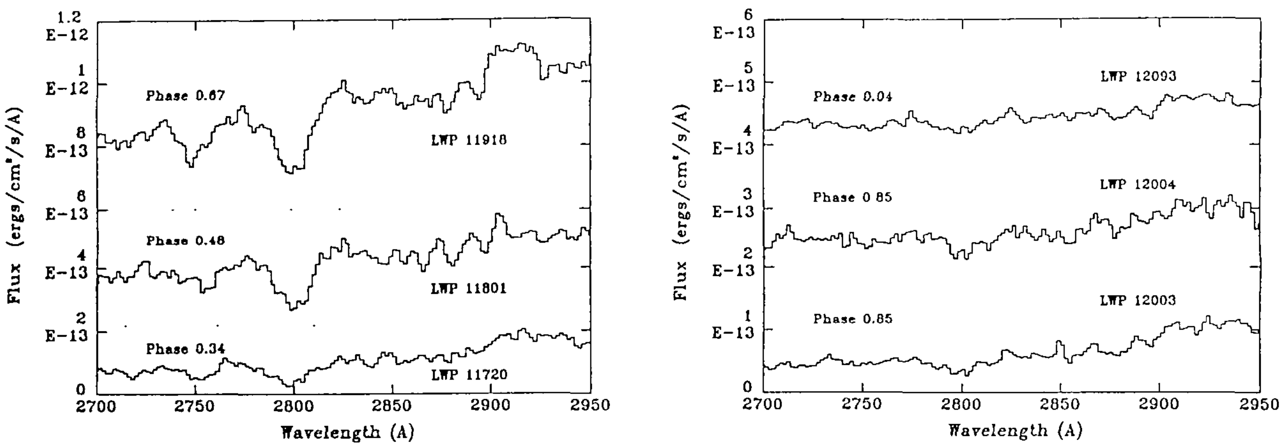

Figure 2:
A series of six low dispersion LWP spectra of AC Her are presented. An offset in flux has been added to each successive spectrum and the corresponding zero flux levels are indicated by the dashed lines. Note the strong Mg II absorption feature at phases 0.48 and 0.67; and that this feature is partially filled in by emission at other phases.

IV ACKNOWLEDGEMENTS

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